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The Research on Quantitative Evaluation of Circular Economy Based on Waste Input-Output Analysis

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Abstract

The importance for sustainable development is increasingly being recognized by the world, and the looking for ways to implement sustainable development has become the focus in domestic and foreign academics. As an effective means of sustainable development, circular economy has been obtained the attention of academics and government. In this study, with the system analysis of development and principle of circular economy, based on the input-output analysis tools, this paper builds an input-output analysis table and the basic evaluation model of circular economy in enterprise.

*Keywords:*Waste; input-output analysis; circular economy; quantitative evaluation

1. Introduction

With global warming and the growing problem of environmental pollution, governments and the general publics take more and more attention to the sustainable development of enterprises. At the same time, the rapid growth of China's material consumption poses profound challenges to sustainable development in the country and the rest of the world. China is now consuming about half of the world's cement, over 30 per cent of its steel and more than 20 per cent of its aluminum. Decoupling economic growth from material consumption and its impacts on human health and ecosystem well-being is a major policy dilemma that China needs to start tackling during its 11th Five-year Program. Transforming production and consumption according to the principles of the circular economy would imply major increases in material use efficiency that should also lead to the reduction of material use and pollution in absolute terms. As we all know, enterprise is the micro-foundation of economic sustainable development of a nation or a region. Therefore, the circular economy of enterprise has become one of the hot and difficult topics in academic research.

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2.The Development Evaluation of Circular Economy and Input-Output Analysis

2.1.The Development and Evaluation of Circular Economy

Circular Economy is a model for economic growth which aims at environmental protection, pollution prevention and sustainable development. Under this model, resources are used with higher efficiency and reused and recycled when possible, so that pollution is minimized and waste is reduced as much as possible. It also involves the transformation of industrial organization and allocation, urban infrastructure, environmental protection, technological paradigms, and social welfare distribution.

The circular economy approach to resource-use efficiency integrates cleaner production and industrial ecology in a broader system encompassing industrial firms, networks or chains of firms, eco-industrial parks, and regional infrastructure to support resource optimization. State owned and private enterprises, government and private infrastructure, and consumers all have a role in achieving the CE.

So far, there have a lot researches on the development and evaluation of circular economy [1-4]. Most of the evaluation system is evaluated the level of recycling economy based on the idea of AHP method by tertiary structure(objectives, criteria, indicators), and the targets of this integrated structure is clear, indicators layer data is relatively easy to obtain, and it is more widely used in a special plan of circular economy in China. In addition, there are many methods of evaluation based on specific indicators, such as the evaluation model of system dynamics, but the integrated indicators are still relatively similar to the macro-indicator, the evaluation of circular economy is difficult to reflect the various sectors association with production and consumption, resulting in the lacks of evaluation of main features of materials recycling between different departments, and it also difficult to take the direct analysis of the environmental and economic benefits because of the circular economy. To fully realize the connotations of circular economy, many scholars take material flow analysis approach to assess the development of circular economy, and have made great progress in recent years.

2.2.Input-Output Analysis

Input-output analysis is one of a set of related methods which show how the parts of a system are affected by a change in one part of that system. It developed by the 20th-century Russian-born U.S. economist Wassily W. Leontief, in which the interdependence of an economy's various productive sectors is observed by viewing the product of each industry both as a commodity demanded for final consumption and as a factor in the production of itself and other goods. Input-output analysis specifically shows how industries are linked together through supplying inputs for the output of an economy. Certain simplifying assumptions are made, such as that productive resources will always be combined in the same proportions to produce any amount of a final product. Then it is possible to determine the total quantities of various goods that must be produced to obtain a given amount for final consumption.

In the current study process [5-9], the main method of input-output analysis covers environmental input-output model (EIO) and waste input-output model (WIO); these two methods are very effective as the tool of waste emissions and governance in economic process analysis, widely used in various countries. Through the joint efforts of academics and entrepreneurs, the theory method and the practical application of input-output analysis has achieved a certain achievements. However, with the application of sustainable development theory and method in economic system, there have more and more the problems and shortcomings for the traditional input-output model in terms of theory and practice.

For example, studies are concentrated in national economy of macro level, or environmental protection and economic development is isolated in study, and there has very little studies on the micro-enterprise level. Even if there are relevant achievements, its model is based on the macro-table style, and is divorced from business accounting. In addition, the design of enterprise's input-output tables only considers the purely economic nature of economic activities, without considering the environmental problems caused by the economic activities. Therefore, the traditional input-output analysis has been difficult to meet the requirements of enterprise environmental management. Besides, due to the restrictions of data collection, the input-output analysis method remains theoretical level, and most of them have not the related application under circular economy.

The existing models for analysis and evaluation can only be described the one-way process of material flow, and can not be described the material and waste circulation in enterprise, which is the most critical mode of circular economy and the key issue that the vast number of researchers hope to resolve. Based on the above analysis, referring the waste input-output analysis model, we summarize and describe the circular economy development model, and construct the quantitative analysis and evaluation model of circular economy development.

3.The Evaluation Model of Enterprise's Circular Economy Based on Waste Input-Output Analysis

3.1.The Basic Framework of the Waste Input-Output Model

The waste input-output (WIO) is a hybrid methodology of LCA that is capable of taking into account all the phases of life-cycle, production, use, and End of Life (EoL). Exclusion of the EoL phase used to be mentioned as a limitation of IO Analysis (IOA) for LCA (while the conventional IOA does not cover the use phase as well, its incorporation is rather straightforward). It, however, does not apply to the WIO because of its explicit consideration of the flow of waste and waste management activities including waste recycling. The WIO corresponds to LCA based hybrid analysis, where the technology matrix of a product system in LCA (in particular the foreground processes that refer to waste management and recycling) is fully integrated with technical coefficients matrix of an economy (the background processes that refer to the traditional flow of goods and services) in IOA [10-16].

At micro level, there have two products in enterprise, namely, products and waste. Waste mainly refers to pollutants in the production process or in the consumption output, but also covers environmentally-sound waste (non-pollutant). Due to different wastes have different damage to the environment, this paper converts the amount of waste into the costs required an environmentally safe state, so the amount of waste is equivalent to the cost of pollution reduction in the model, namely, pollution discharge intensity. Environmentally sound waste may still bring to economic benefits through recycling. Waste input-output model of this paper consists three parts, which is showed in Table 1.

The meaning of each item in Table 1 is showed as follows:

Z_{ij}, P_{ij}, P_{ij}^*, respectively, is the waste in production sector i which is used in the production process of production sector j, the payment to sector i of the waste used by departments j, the purchased costs of resource and general products the case of department j do not use this part of the waste. Assuming the production sector needs pay for its pollutants, then P_{ij} should exist between $-Z_{ij}$ and P_{ij}^*. $Z_{ij} = 0$, and $P_{ij}^* - P_{ij}$ is waste.

EX_i, EC_i, ER_i, respectively, the amount of pollutants elimination which is generated by production sector i, the amount of pollutants reduction in the consumption which is produced by production sector i in the both inside and outside research area, the amount of pollutants produced by pollution eliminated department when it reduce the pollutants of the production sector i.

$Con_i, ICon_i$, respectively, the amount of waste generated in the product course of the production sector i which is transferred from the outside of research area and the inside consumption in research area.

W_i means the remains of waste after reduced by the internal department and the waste production sector in the production sector i.

OW_i means the direct or indirect maximum total contribution to waste output of the research area in the production sector i.

$$OW_i = \sum_{j=1}^{n} Z_{ij} + ER_i + W_i + Con_i + ICon_i \tag{1}$$

RX_i means the amount of natural resources used in the production process of the production sector i. O_i, O_i^*, respectively, the costs of waste which produced by non-production sectors in the production process of the production sector i and the purchase costs of resources which come from that departments replaced by this part of the waste or general product. RW_i represents the total amount of resources input or general products in the case of the production sector i do not use waste, namely, $RW_i = \sum_{j=1}^{n} P_{ji}^* + RX_i + O_i^*$.

3.2.The Calculation of the First Quadrant and Evaluation of Environmental Benefits

For inspecting the waste reduction based on the implementation of circular economy in the production sector, this paper defines the coefficient of waste cumulative reduction a_i (also known as the cumulative reduction factor of pollutants), so it is,

$$a_i = \frac{\sum_{j=1}^{n} z_{ij}}{OW_i} \qquad i, j = 1, 2, \cdots, n \tag{2}$$

a_i is the proportion of waste reduction within the production department in waste total output. a_i is larger, it shows that there have the more significant effects for the pollutant emission reduction in productive sector i based on the circular economy model. Then defining the waste reduction rate P of regional recycling economy, it represents the improvement for the regional environment through the implementation of recycling economy in all the productive sectors, namely,

$$a_i = \frac{\sum_{j=1}^{n} z_{ij}}{OW_i} \qquad i, j = 1, 2, \cdots, n \tag{3}$$

It defines the waste direct reduction coefficient (a_{ij}) within the production sector firstly.

$$a_{ij} = \frac{z_{ij}}{OW_j} \qquad i, j = 1, 2, \cdots, n \tag{4}$$

a_{ij} means the waste reductions in sector i in per unit waste production of the production sector j. As only referring the input-output matrix method to assess situation, it does not discuss the relationship between the final product and total production output, and it is not required the feasible solution for the vector of any final demand, there exist a_{ij} >1, it does not affect the model evaluation.

Thus the paper defines the direct reduction coefficient matrix A and the complete reduction coefficient matrix B:

$$A=\left\{a_{ij}\right\}=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{5}$$

$$\begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix}=B=(I-A)^{-1}-I \tag{6}$$

It is similar to the traditional input-output method, the b_{ij} in complete reduction coefficient matrix B is defined as the waste complete reduction coefficient within the production sector, which indicates that the amount of waste can be reduced directly and indirectly in sector i while per unit of waste output produced in the production sector j .

Defined the environmental benefit contribution rate of recycling economy in production sector b_j , and $b_j=\sum_{i=1}^{n} b_{ij}$, the specific meaning is the amount of waste can be reduced directly and indirectly in all production sectors while per unit of waste output produced in the production sector j . If b_j >1, through the mode of circular economy, in fact, the sector j bear the role to eliminate pollution in the region, if b_j <1, it is the net sewage department in the region.

The calculation of the first quadrant mainly reflects the effects of pollutant reduction through the recycling mode of circular economy in the production sector, as well as the production sector's contribution to improve the regional environment situation.

4.Conclusion

Based on input-output analysis tools, the author establishes the quantitative evaluation model which describes waste output, exchange and releases in production, consumption during a period of time, and it can describe the development situation of circular economy, and thus develop the related evaluation index of circular economy development. Compared to the general evaluation model of circular economy, this method can analyze the benefits and contributions resulting from the reduction and elimination of wastes, and it has a more significant effect on the quantitative analysis model of circular economy and environmental governance. Of course, as the complexity of the process of resource recycling and the process of production and operations, this model still has some flaws and weaknesses, needs further study in future.

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TABLE I. THE INPUT-OUTPUT TABLE BASED ON THE WASTE

Input	**Waste output**										
	Production area				**Pollution eliminated department**			Waste remains in production area	**Consumption area**		Total waste output in area
	Department 1	Department 2		Department n	Pollution reduction in product	Pollution reduction out of	Pollution produced by itself		waste output inside area	waste output outside area	

					ion area	product ion area					
Depart ment 1	Z_{11} P_{11},P_{11}	Z_{12} P_{12},P_{12}	W_1	Z_{1n} P_{1n},P_{1n}	EX_1	EC_1	ER_1	W_1	Con_1	$ICon_1$	OW_1
Depart ment 2	Z_{21} P_{21},P_{21}	Z_{22} P_{22},P_{22}	W_2	Z_{2n} P_{2n},P_{2}	EX_2	EC_2	ER_2	W_2	Con_2	$ICon_2$	OW_2
……											
Depart ment n	Z_{n1} P_{n1},P_{n1}	Z_{n2} P_{n2},P_{n}	W_n	Z_{nn} P_{nn},P_{nn}	EX_n	EC_n	ER_n	W_n	Con_n	$ICon_n$	OW_n
Resour ce and general product s	RX_1	RX_2		RX_n							
The product ion depart ment outside area	O_1,O_1^*	O_2,O_2		O_n,O_n							
Waste input	RW_1	RW_2		RW_n							